Systems Safety, Reliability, and Risk Assessment

Task 2
Safety and Launch Vehicle Review Support

Final Report

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Prepared For
Advanced Space Transportation Program
2nd Generation Reusable Launch Vehicles
George C. Marshall Space Flight Center
National Aeronautics and Space Administration

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Introduction

This report summarizes support provided by Science Applications International Corporation (SAIC) to the NASA/Marshall Space Flight Center (MSFC). Work under this contract was performed in support of the Advanced Space Transportation Program and the Second Generation RLV Program Office.

Background and Objectives

The overall objective of this effort by SAIC was to provide MSFC with support in evaluating 2nd generation launch vehicles in regards to the safety and reliability improvements offered by advanced systems and architectures. This support was provided through a number of mediums:

1. SAIC supported the Inter-center Systems Assessment Team by leading the Crew Safety and Vehicle Reliability Sub-team. Gaspare Maggio of the SAIC Systems Technologies and Applications Division served as the Crew Safety and Vehicle Reliability Sub-team Lead and was supported by a team of NASA and SAIC personnel. The team participated in two teleconferences a week and provided analyses and consultation on an as-requested basis.

2. SAIC participated in the Space Transportation Architecture Studies (STAS) Technical Interchange Meetings in which five main contractors (Boeing, Lockheed, Space Access, Orbital Sciences, and Kelly Space Technologies) brief NASA regarding their respective proposals for 2nd Generation Launch Vehicles and Space Access Architectures.

3. SAIC provided the management of the Advanced Space Transportation Program and the Second Generation Program Office with suggestions for improving safety and reliability processes and risk management as the development of 2nd Generation Vehicles progresses through various design phases.

4. SAIC recommended metrics and evaluation criteria to the Second Generation RLV Program Office to assist in measuring contractor's (e.g. Boeing, Lockheed, Space Access, Orbital Sciences, and Kelly Space Technologies) performance in the area of safety and reliability and to for gauging progress as vehicle and technologies are further tested and developed.

5. SAIC participated in three ISAT technology assessment workshops. The technology assessment workshops were held at NASA Marshall Space Flight Center (MSFC) in the Collaborative Engineering Center (CEC), building 4203 sixth floor during the following dates: September 11th-15th, 2000, November 13th –17th, 2000, and February 26th- March 2nd, 2001. The first two workshops analyzed technology impacts on a Two Stage to Orbit (TSTO) Bimese Vehicle. The last workshop analyzed a Single Stage To Orbit (SSTO) Vehicle. Each vehicle was designed to perform cargo (35K) delivery to the International Space Station (ISS) to an orbit of 250 nautical miles x 51.6° inclination.

   Each Technology Assessment Workshop analyzed the following technologies:

   <u>September 11th- 15th, 2000 TSTO assessment</u>

   Main Propulsion
   Densified Propellant & Main Propulsion
   Airframe Structure
   Thermal Protection
   Undercarriage
   Electrical
   IVHM-Auto Leak Detection

   <u>November 13th- 17th, 2000 TSTO assessment</u>

   Advanced Engine
   Densified Propellant
   Advanced Engine and Densified Propellants
   Proton Exchange Membrane Fuel Cells (PEM_FC)
   Propulsion Integrate Vehicle Health Management (PIVHM)

   In addition to the required technologies, the following advanced engine sensitivity cases were analyzed during the November assessment:

   Thrust to Weight 60
   Thrust to Weight 80
   Specific Impulse 440
   Specific Impulse 455
   Gross Lift-Off Weight (GLOW) less 5,000 lbs.
   Gross Lift-Off Weight (GLOW) less 10,000 lbs.

February 26th- March 2nd, 2001 SSTO

NBPP
SSME
NBPP and SSME
State of the Art (SOA) Structure
SOA TPS
SOA Fuel Cell
High Voltage/ High Power (HV/HP) Power Manage And Management (PMAD)

In addition to the required technologies, the following engine sensitivity cases were analyzed during the February assessment:

Engine Out
Engine 60 T/W
Engine 75 T/W
Overhaul Up
Overhaul Down
Engine ISP 445
Engine ISP 455

The general conclusions are as follows:

The initial reliability assessment showed that the main propulsion remains continues to be a major risk contributor. A large reliability benefit may be gained from replacing the Auxiliary Power Units (APU) and associated hydraulic systems.

Most sensitivity cases showed minimal impact on the top level Loss of Vehicle (LOV) risk.

6. SAIC began a Probabilistic Risk Assessment (PRA) of the X-34 experimental hypersonic vehicle that was being built and flown by Orbital Sciences. The objective of the study was to assess the first flight and recommend methods for reducing the risk of losing the vehicle or failing to gather sufficient flight data to claim the mission a success. The X-34 program was cancelled before completion of this task but a lessons learned document was produced at the request of the customer and is included as an attachment.

Specific Products and Deliverables

For the most part, the support provided by SAIC was in the form of real-time consultation and recommendations, however, SAIC has provided the customer a number of specific products produced in support of the tasks discussed in the previous section. These products are as follows and most have been provided in previous reports:

1. *INTEGRATED SPACE TRANSPORTATION PROGRAM SAFETY AND RELIABILITY EVALUATION OF SECOND GENERATION REUSABLE LAUNCH VEHICLES PROPOSED AS PART OF THE SPACE TRANSPORATION ARCHITECTURE STUDY*: This presentation was provided to document the assessment by the SAIC lead ISAT Safety and Reliability Team of advanced technology Vehicle concepts proposed by Boeing, Lockheed, Space Access, Orbital Sciences, and Kelly Space Technologies.

2. *ISTP/ISAT SHUTTLE-DERIVED VEHICLE CONTRACTOR EVALUATION - SAFETY & RELIABILITY*: This presentation was provided to document the assessment of Shuttle-Derived Vehicle concepts proposed by Boeing and Lockheed by the SAIC lead ISAT Safety and Reliability Team.

3. *EVALUATION OF STAS CONTRACTOR NEW RLV LOV ESTIMATES*: This presentation was provided to document the SAIC-led assessment of contractor conducted reliability analyses of their proposed new RLVs.

4. *EVALUATION OF STAS CONTRACTOR SDV RLV LOV ESTIMATES*: This presentation was provided to document the SAIC-led assessment of contractor conducted reliability analyses of their proposed Shuttle-Derived RLVs.

5. *ISAT CREW SAFETY AND VEHICLE RELIABILITY TEAM INTERACTION MATRIX*: This document was provided to the ISAT integration team to show the interfaces that would have to be established between the safety and reliability team and other ISAT teams to facilitate the systems analyses process.

6. *PROPOSED 2nd GENERATION LAUNCH SYSTEM PROGRAM RELIABILITY METRICS/PROGRESS ASSESSMENT METHODOLOGY*: This presentation put forth the general methodology and ground rules for establishing metrics for tracking safety and reliability in 2nd Generation vehicles – this process is a continuing effort.

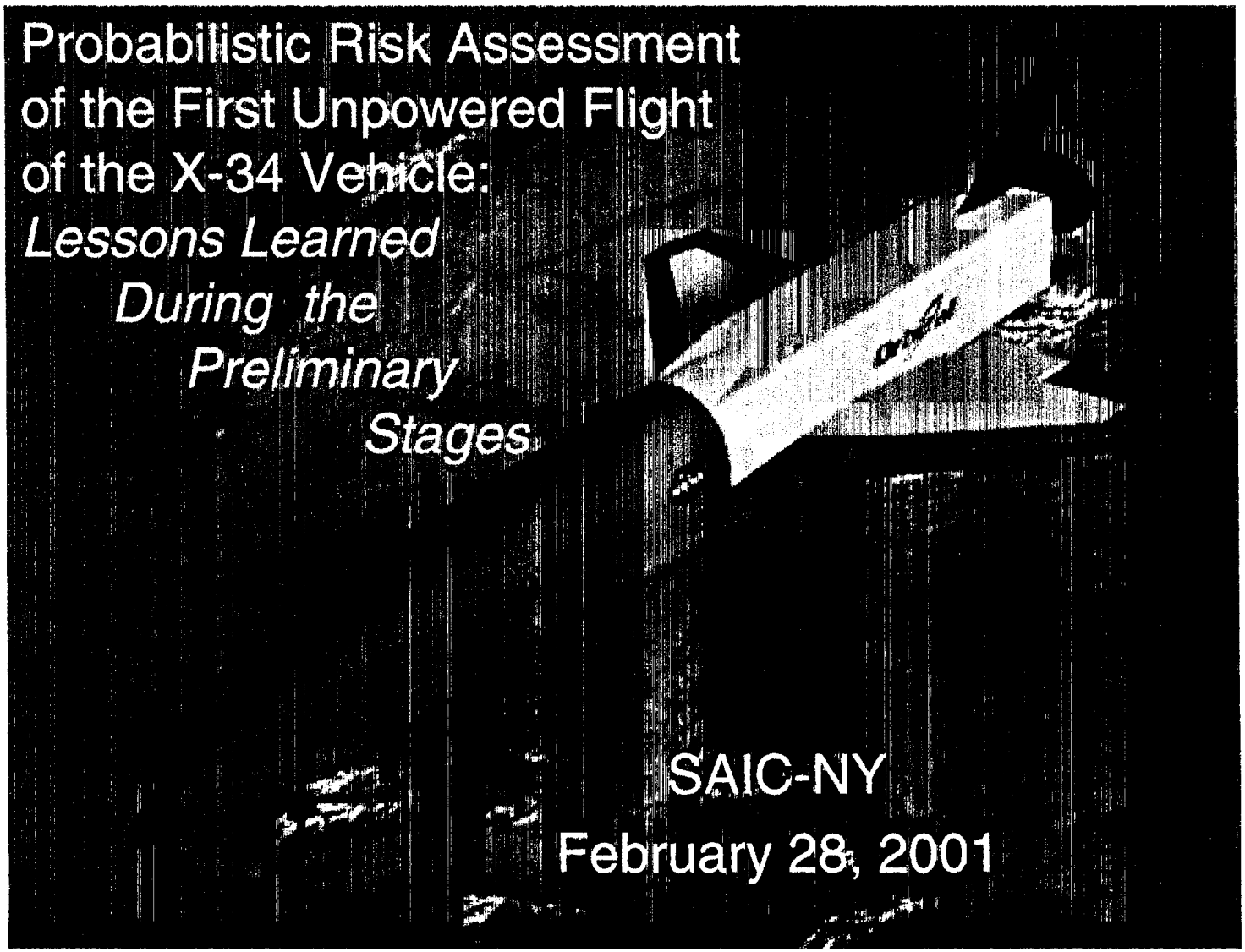
7. *ISAT 2ND GEN RLV SAFETY AND RELIABILITY PROCESS*: This document shows the SAIC safety and reliability analyses process that is being

implemented in the evaluation of ISAT developed reference vehicles and how it fits into the entire systems analysis process.

8. *INTER-CENTER SYSTEMS ASSESSMENT TEAM 2ND GENERATION RLV STATUS REVIEW ON CREW SAFETY AND VEHICLE RELIABILITY*: This presentation was presented to the managers of the 2nd Generation RLV Program Office and detailed SAIC's analysis of a Single-Stage-to-Orbit (SSTO) vehicle.

9. *2ND GENERATION RLV SAFETY AND RELIABILITY METRICS*: This presentation was provided to recommend metrics and evaluation criteria to the Second Generation RLV Program Office to assist in measuring contractor's (e.g. Boeing, Lockheed, Space Access, Orbital Sciences, and Kelly Space Technologies) performance in the area of safety and reliability and to for gauging progress as vehicle and technologies are further tested and developed.

10. *LESSONS LEARNED DURING THE PRELIMINARY STAGES PROBABILISTIC RISK ASSESSMENT OF THE FIRST UNPOWERED FLIGHT OF THE X-34 VEHICLE*: This presentation discussed the lessons learned as SAIC conducted a Probabilistic Risk Assessment of the X-34 vehicle and is attached for review.

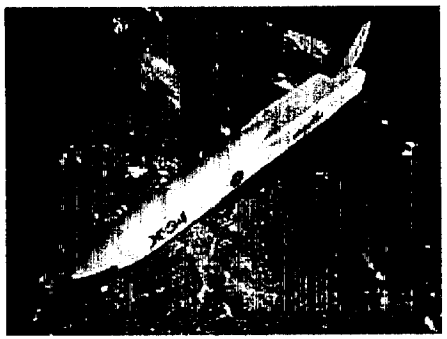


Probabilistic Risk Assessment of the First Unpowered Flight of the X-34 Vehicle: *Lessons Learned During the Preliminary Stages*

SAIC-NY

February 28, 2001

Ingredients for a Successful PRA



- Identification of Mission Objectives
- Definition of PRA Scope & Objectives
- Kick-Off Meeting
  - Create Timeline and Tie to Project Critical Events
  - Define Roles of Key PRA Personnel
  - Systems Experts Need to Be Made Aware of Their Role in the PRA - Identify Points of Contact
  - Collect Preliminary Information Needed to Begin PRA Work
  - Contract Issues for all Involved Parties should be at least in the final stages of resolution

NASA SAIC Orbital

System and PRA Contractor Interfaces

Any Contractor involved in the project needs to become part of the PRA Process:

- All personnel should be made aware of PRA objectives
- Key systems experts should be educated on fundamentals
- System "owners" should agree to meeting milestones

This is essential because a lack of communication can inhibit progress and compromise the objectives of the PRA .

X-34 PRA Accomplishments

The goal was to:

Perform a Probabilistic Risk Analysis of the X-34 Vehicle for Unpowered Drop Flight and Rank Significant Risk Drivers

What SAIC accomplished:

(Prior to January 8th, 2001 work stoppage to await technical review by Orbital systems experts):

- Developed *Master Logic Diagram*
- Identified Preliminary Functional Failure *Initiators*
- Developed Preliminary *Event Trees* and *Fault Trees*
- Preliminary *Quantification* of Fault Trees

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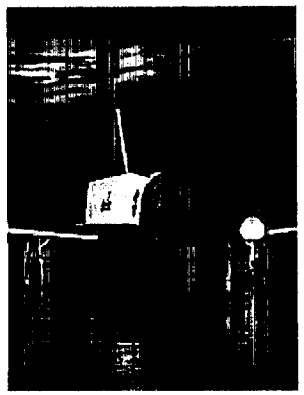
Pitfalls of the X-34 PRA

Although important documents were received from NASA MSFC:



- Hydraulic FMEA Documents
- Avionics FMEA Documents
- "X-34 Current Document Status Report"
- X-34 System Design Freeze

SAIC never received any information from Orbital due to lack of contractual agreements to provide this information:

- SAIC requested approximately fifty items from Orbital's "X-34 Current Document Status Report"

- No technical review meetings with system experts was held to exchange information